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Research Paper

Design and optimization of 2x2 corporate-series fed microstrip antenna array

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Abstract

The limitation of microstrip patch antenna is relatively low gain and narrow bandwidth. By using the microstrip patch antenna array antenna performance can be improved. In this paper design and stimulation of a 4 element rectangular microstrip patch array is described and the performance of antenna array is optimized by varying patch element dimensions. Antenna array is designed to operated at the frequency of 10 GHz. The corporate-series feed network is implemented for feeding patch elements. The 2x2 antenna array is implemented on FR4 substrate with 1.588mm thickness and dielectric constant of 4.4.The stimulation and performance analyze of antenna is done using Ansoft High frequency structure simulator software. Finally, comparison of antenna array characteristics before and after optimization is presented.

Keywords: *Use about five key words or phrases in alphabetical order, Separated by Semicolon.*

1. Introduction

Microstrip Patch Antennas have a lot of advantages over other antennas due to their low profile, light weight, low production cost, and are easily well-suited with optoelectronic integrated circuits (OBICs) and microwave monolithic integrated circuits (MMICs). Researchers are showing more interested towards microstrip antennas [1] dues to these features of microstrip antenna. Nowadays, microstrip patch antennas are used in wide range of applications such as in wireless communication and biomedical diagnosis. In recent years, the widespread proliferation of wireless communication has augmented the demand for compact broadband antennas for handheld devices, satellite systems, etc. But it has a disadvantage of producing narrow bandwidth and low gain.

To overcome the inherent limitation, many techniques have been planned and investigated [1].X-band frequency range as defined by IEEE for radar application includes the range from 8 to 12 GHz. This frequency range is widely used in applications such as military, civil, weather forecasting and monitoring, police radars for vehicle speed detection, etc. High resolution imagery with fine resolution and discrimination can be obtained from the shorter wavelength of X-band [9]. The Xband frequency range for satellite and RADAR (Radio Detection and Ranging) communication requires increased operating bandwidth with finest size [8]. In communication engineering, the X -band frequency range is somewhat indefinitely placed at approximately 7.0 to 11.2 GHz.

In general, there are different shapes for Microstrip Patch Antenna is available, such as Disc sector, Square, Rectangular, Elliptical, Dipole, Circular, Triangular, Circular ring and Ring sector. Each design has its own merits and demerits. In this paper rectangular patch element is used. To overcome limitation of antenna , an antenna array is implemented, which is optimized by varying patch dimensions.

In this paper implementation of a 2x2 rectangular microstrip patch antenna array is described. Here patch elements are fed by the edge feeding technique. Also, corporate-series feed network is implemented for feeding each patch elements. The substrate material used for the designing is the FR4 with dielectric constant of 4.4. Then, antenna structure is optimized for improving antenna characteristics. Lastly, performance of antenna structure before and after optimization is analyzed. The Ansoft High Frequency Structure Simulator (HFSS) software tool is used for the designing and analyzing of the antenna structures.

This paper is organized in the following way. The section II gives brief description on the microstrip patch antenna array design and optimization. The simulation and performance analyze of designed antennas is presented in section III.

2. Microstrip antenna design and optimization

This paper presents the design and stimulation of 2x2 corporate-series feed microstrip patch antenna array and its optimized structure. The proposed antenna is intended to operate at 10 GHz frequency. The substrate material has height (h) of 1.588 mm and dielectric constant (ε_r) 4.4. The length (L) and width (W) of the patch [1], [2], [4], [5] is obtained by using equations (1)-(4).

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}} * \sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}\mu_0\varepsilon_0}} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412h * \frac{(\varepsilon_{eff}+0.3)}{(\varepsilon_{eff}-0.258)} * \frac{\left(\frac{W}{h}+0.264\right)}{\left(\frac{W}{h}+0.8\right)} \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+12\frac{h}{W}}} \tag{4}$$

Where f_r is the resonant frequency, h is the height of substrate, ε_{eff} is the effective dielectric constant and ΔL is the length extension. The characteristic impedance of the patch is given by

$$Z_a = 90\frac{\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \tag{5}$$

The edges of patch elements are separated at a distance of the half the wavelength (λ). For a given characteristic impedance Z_0 and dielectric constant ε_r, the relation between strip having width W and dielectric layer with the thickness h is given by [3]

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A}-2} \text{ for } \dfrac{W}{d} \le 2 \\ \dfrac{2}{\pi}\left[\begin{matrix} B-1-\ln(2B-1)+ \\ \frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)0.39-\frac{0.61}{\varepsilon_r}\right\} \end{matrix}\right] \text{ for } \dfrac{W}{d} > 2 \end{cases} \tag{6}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \tag{7}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{8}$$

In this project, the power is fed to the antenna array elements by using the microstrip transmission line method [1], [6]. The radiated fields of the E-plane [4], [7] for a single element patch is expressed in (9).

$$E = j\frac{k_0 W V_0 e^{-jk_0 r}}{r\pi}\left\{\frac{\sin\left(\frac{k_0 h}{2}\cos\varphi\right)}{\frac{k_0 h}{2}\cos\varphi}\right\}\cos\left(\frac{k_0 h}{2}\cos\varphi\right) \tag{9}$$

Where W is the width of the patch antenna, $V_0 = hE_0$ is the voltage across radiating slot. h is the substrate height, $K_0 = 2\pi/\lambda$ and r is the far field distance from the antenna. The array factor equation of this antenna is given in Equation (10).

$$FA = \frac{\sin^2\left(N\pi\left(\frac{d_x}{\lambda}\right)\sin\theta_a\right)}{N^2\sin^2\left(\pi\left(\frac{d_x}{\lambda}\right)\sin\theta_a\right)} * \frac{\sin^2\left(M\pi\left(\frac{d_y}{\lambda}\right)\sin\theta_e\right)}{M^2\sin^2\left(\pi\left(\frac{d_y}{\lambda}\right)\sin\theta_e\right)} \tag{10}$$

Where d_x and d_y represents element spacing in x and y direction N is the number of vertical elements of array that gives rise to the azimuth angle, θ_a and M is equal to number of horizontal elements of array that gives rise to the elevation angle, θ_e. The dimension of substrate used is 35.568 mm (width) and 33.668 mm (length). Using equations (1) to (4) dimensions of patch element are found out. The computed length and width of patch antenna are 6.4 mm and 9.1 mm respectively. After computation the designed antenna structure before optimization is shown in the Figure 1. The next step is the optimization of antenna structure, for that length and width of the antenna are varied. Also, horizontal and vertical distance between patches are varied. Among various design cases, antenna structure which shown better performance is given in fig.2.

3. Analysis results

The 2x2 microstrip patch antenna array structures are implemented in HFSS simulation software version 15.0. The antenna is designed for 10GHz operating frequency. And the substrate material used is the FR4 with relative permittivity of 4.4 and its height is 1.588mm. For analyzing microstrip patch antenna, driver solution setup is created with solution frequency at 10 GHz. Along with that a frequency sweep is created of type interpolating and with a frequency sweep range of 8 to 12 GHz. The results obtained for antenna before and after optimization is given next.

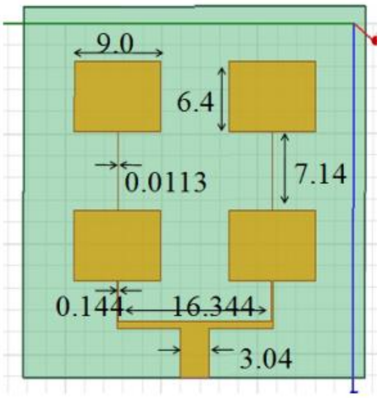

Fig. 1: Microstrip Patch Antenna Array before Optimization.

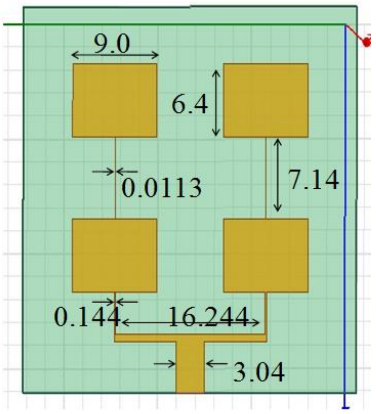

Fig. 2: Microstrip Patch Antenna Array after Optimization Return Loss

The return loss is generated for the frequency range 8 to 12 GHz for the designed antennas. Fig.3 and 4 show the return loss obtained for both antenna structures. For antenna structure in Fig.1 has the lowest return loss is found to be -19.666 dB at the 9.96 GHz frequency whereas for second structure return loss obtained is -25.2097 dB at the 9.94GHz frequency.

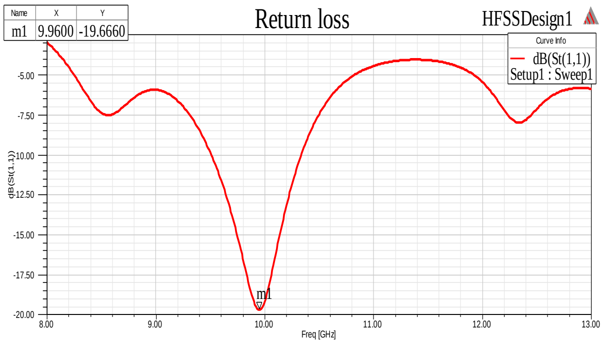

Fig. 3: Return Loss of 2x2 Patch Antenna Array.

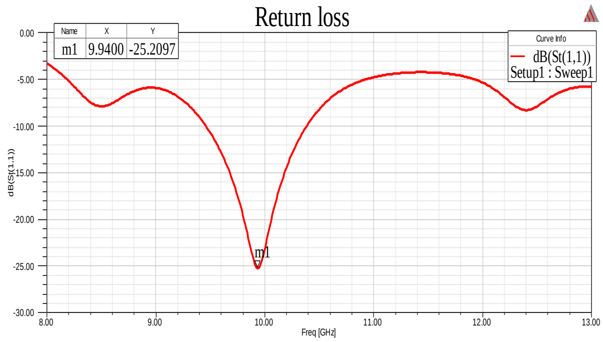

Fig. 4: Return Loss of Optimized Antenna Array.

Gain

Fig. 5 and 6 show the 2D plot of total gain vs theta for the patch antenna array structures. Here the theta varies for -180 to 180 degrees and phi is equal to 0 degree and 90 degrees. The figure represents gain obtained in E (phi= 0 degree) and H plane (phi= 90 degree). The maximum total gain is found to be 9.5333 dB before optimization and after optimization obtained maximum gain is 9.6115 dB.

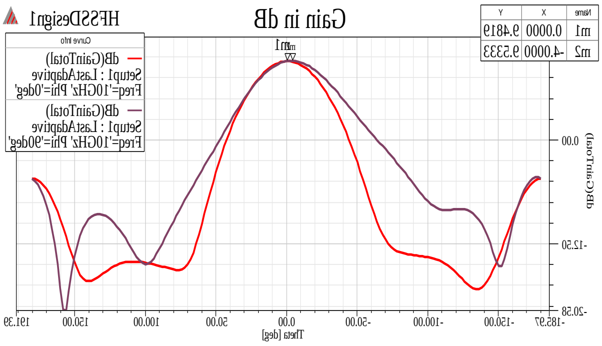

Fig. 5: 2D Gain before Antenna Optimization.

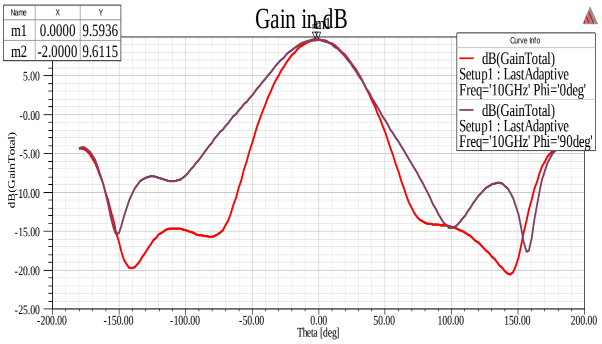

Fig. 6: 2D Gain after Antenna Optimization.

Radiation pattern

Radiation patterns for the patch antenna arrays is shown in Fig.7 and 8. The figure shows the radiation pattern obtained in E-plane and H-plane.The 3-dBbeamwidth (or half-power beamwidth) of an antenna is typically defined for each of the principal planes (E and H Plane). The 3-dB beamwidth in each plane is defined as the angle between the points in the main lobe that are down from the maximum gain by 3 dB. From the radiation pattern plots both antenna have same 3-dB beamwidth which is found to be 46 degrees in E-plane and 52 degrees in H-plane.

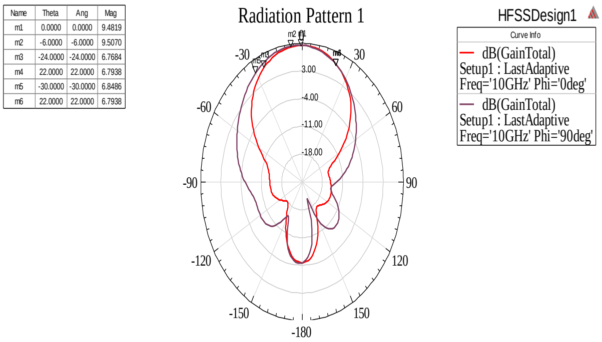

Fig. 7: Radiation Pattern of 2x2 Patch Antenna Array.

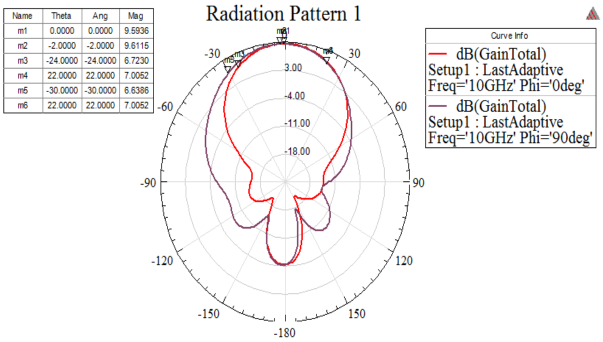

Fig. 8: Radiation Pattern Obtained for Optimized Antenna Structure.

Voltage standing wave ratio (VSWR)

The VSWR plots of microstrip patch antenna is shown in Fig.9 and 10. Figure 9 shows VSWR plot of antenna with actual parameter, whereas fig.10 represents VSWR plot after antenna optimization. For antenna structure before optimization the magnitude of VSWR is less than 2 for frequency ranges from 9.5 GHz to 10.35 GHz, which means antenna array has an impedance bandwidth of 0.85 GHz. For the second case, the magnitude of VSWR is lower than 2 for frequencies from 9.44 GHz to 10.4 GHz, so impedance bandwidth for this case is 0.96 GHz.

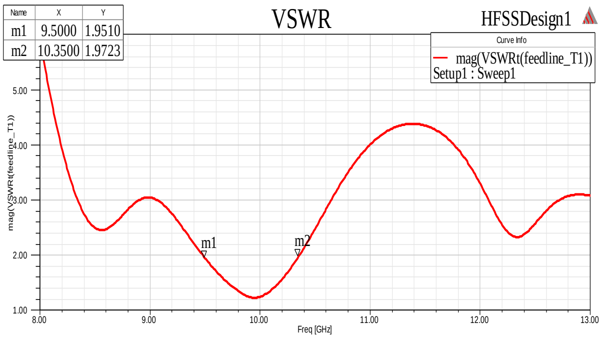

Fig. 9: VSWR Plot of 2x2 Patch Antenna Array.

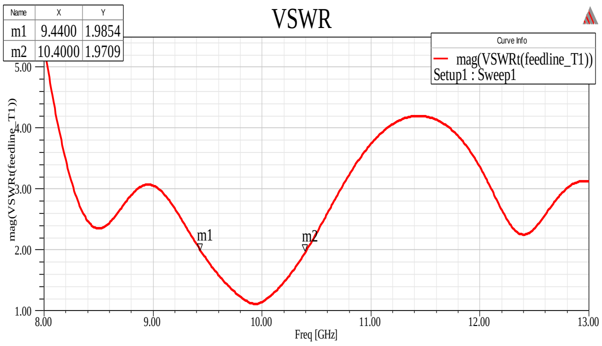

Fig. 10: VSWR Plot of Optimized Antenna Array.

From results, it can be seen that antenna characteristics have been improved. In Table 1 the results obtained for both antennas are summarized.

Table 1: Comparison of Two Antenna Structures

Performance Parameter	Before Optimization	After Optimization
Return Loss	-19.666 dB	-25.2097 dB
Total Gain	9.5333 dB	9.6115 dB
3dB Beamwidth in E-plane	46^0	46^0
3dB Beamwidth in H-plane	52^0	52^0
Impedance Bandwidth	0.85GHz	0.96GHz

4. Conclusion

The 2x2 microstrip patch antenna arrays is designed and its performance is evaluated using HFSS. The results shows that an improvement in antenna characteristics can be easily obtained by changing computed patch antenna dimensions. With optimized antenna design 6 dbimprovement in returned loss is obtained, whereas gain increased by 0.08dB compared to the antenna designed using equations. But in case of impedance bandwidth optimized antenna shows an improvement of 110MHz. In future, physical implementation of patch antenna array has to be done and its performance has to be evaluated.

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